A Method of Reducing Aeroelastic Effects of Highly Swept Wings

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Symbols

$C_{L\alpha}$	=	lift-curve slope based on projected plan area, per deg.
dC_D/dC_L^2	=	drag-rise factor
C_{D_0}	=	minimum drag coefficient based on projected plan area
$(L/D)_{max}$	=	maximum lift-drag ratio
dC_m/dC_L	=	aerodynamic center location from $0.35\bar{c}$ in terms of $\bar{c}$ (negative values for rearward locations)
A	=	aspect ratio
b	=	wing span of flat wing, in.
c	=	mean aerodynamic chord, in.
E	=	modulus of elasticity, lb./sq. in.
I_0	=	moment of inertia of the flat wing at section $I_0 - I_0$ of Fig. 1, in.[4]
M	=	Mach number
q	=	free-stream dynamic pressure, lb./sq. in.

The greatest efficiency for a lifting surface at supersonic speeds, according to the theoretical considerations of reference 1, can be attained if the leading edge is swept well behind the Mach cone and the highest aspect ratio which is structurally possible is employed. Such a wing, designed for a Mach number of 3.0, would have 80° of sweepback.[2] Aeroelastic effects have been shown[3] to be considerable for a wing with 60° of sweepback and designed for a Mach number of 2.0. The wing[2] shown in Fig. 1 was found theoretically to have considerable loss in maximum lift-drag ratio attributable to aeroelasticity. This wing has 12-per cent-thick Clark-Y airfoils normal to the wing leading edge. If it were of solid aluminum and flying at a dynamic pressure of 2,400 lbs./sq.ft. (flexibility parameter $qb^4/EI_0 = 7.8$), analysis indicates that the wing would deflect so as to reduce the maximum lift-drag ratio about 30 per cent.

In an attempt to improve the aerodynamic characteristics, calculations were made for this wing with each panel warped to conform with the curvature of a cylinder having its axis parallel to the flight direction (Fig. 1). Stiffening the wing in this manner would result in no change in local angle of attack and only small changes in minimum drag.

The linear theory of reference 4 was used to calculate the surface loading for the flat rigid wing. Surface loadings for the flat flexible and the warped flexible wings were derived from those for the rigid wing by an iteration process involving load adjustments for the calculated wing deflections. No more than four approximations were found necessary to arrive at the final loading curves. In all cases the wing panels were treated as simple beams. Values of the lift and pitching moments were obtained by mechanical integration of the loading curves.

The following assumptions were made in the calculations:

(a) Modulus of elasticity is constant along the wing span.

(b) Airfoil taper of the flat wing is uniform along the span.

(c) The warped wing is derived from the flat wing by warping each panel to conform with the portion of a circular cylinder shown in Fig. 1.

(d) A negligible deflection occurs ahead of I_0-I_0 in Fig. 1.

(e) Center of load at each spanwise station is coincident with the neutral axis; thus zero twist about the neutral axis is assumed. (This assumption is considered valid because the analysis indicated that the maximum change in local angle of attack due to twisting was less than 1 per cent of the value due to bending.)

Although the curvature of the warped wing is not considered to be optimum, the wing warpage was so effective that no significant wing distortion or change in the aerodynamic characteristics due to aeroelasticity was calculated for values of qb^4/EI_0 up to 7.8 (see Fig. 1). For small values of qb^4/EI_0, the warped wing has a slightly smaller $(L/D)_{max}$ than the flexible flat wing because of the loss in lift associated with the smaller projected area.

It was noted in the analysis that for a given sized wing, as the dynamic pressure was increased, more of the wing tip of the flat wing became completely unloaded; a result which was unaltered by an angle-of-attack change within the range of validity of linear theory.

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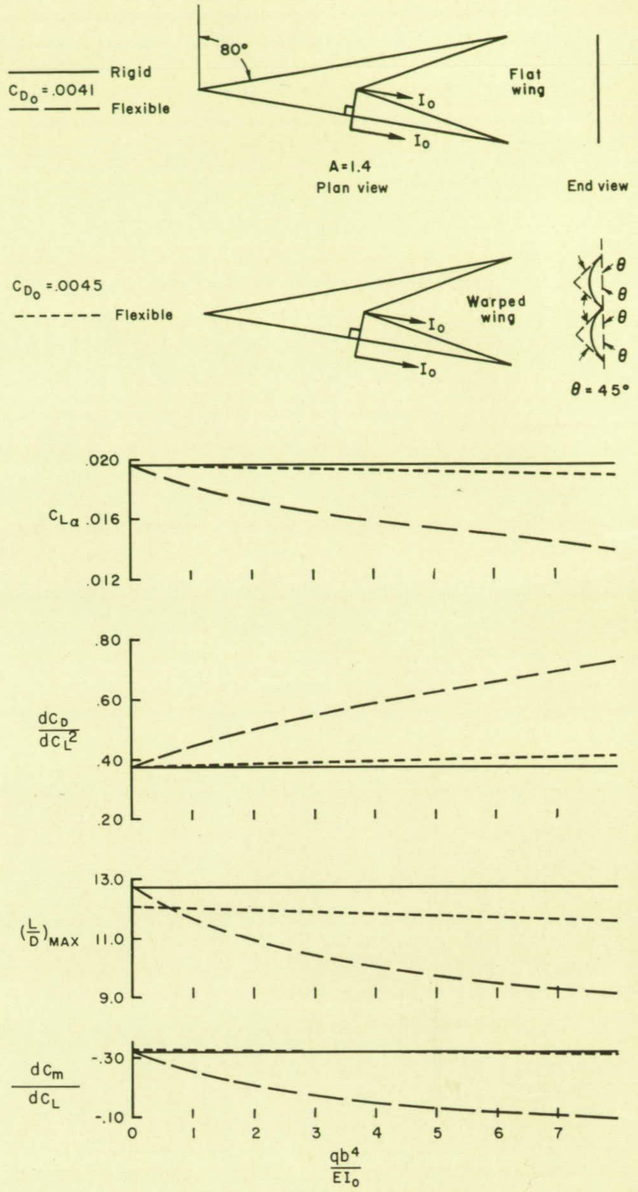

Fig. 1. Estimated effect of flexibility on the aerodynamic characteristics of a highly swept arrow-wing with full leading-edge thrust assumed; $M = 3.0$.

References

[1] Jones, Robert T., *Estimated Lift-Drag Ratios at Supersonic Speed*, NACA TN 1350, 1947.

[2] Katzen, Elliott D., *Idealized Wings and Wing-Bodies at a Mach Number of 3*, NACA TN 4361, 1958.

[3] Frick, C. W., and Chubb, R. S., *The Longitudinal Stability of Elastic Swept Wings at Supersonic Speeds*. Journal of the Aeronautical Sciences, Vol. 17, No. 11, November, 1950.

[4] Cohen, Doris, *Formulas for the Supersonic Loading, Lift and Drag of Flat Swept-Back Wings With Leading Edges Behind the Mach Lines*, NACA Rept. 1050, 1951.